

# Freshwater inflows to estuaries: Organic carbon and microbial food webs in south-east Australia



James N. Hitchcock

A thesis in fulfilment of the requirements  
for the degree of Doctor of Philosophy

March 2015

Centre of Environmental Sustainability  
School of the Environment  
University of Technology Sydney



## Certificate of original authorship

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text. I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature

Date



## Acknowledgements

I have had an amazing time completing this research. I am immensely appreciative for having the privilege to devote a period of my life to this intellectual pursuit.

I am deeply grateful for the guidance and support from my supervisor Dr Simon Mitrovic. Since I started working with Simon during my honours he has provided a great combination of intellectual rigor, technical expertise and academic freedom. Whether sitting in a boat in the rain, meeting over coffee, on long drives to the south coast or the sampling beers after field work, Simon made this work not only possible, but incredibly enjoyable.

I would like to acknowledge the support provided through the Peter Cullen Scholarship funded by NSW Office of Water, Sydney Water, State Water, Sydney Catchment Authority and Hunter Water. Without the financial support of this scholarship much of this research would not have been possible. I would like thank scholarship coordinator Simon Williams for his support and advice throughout my candidature. I would also like to thank the Wentworth Group of Concerned Scientists and other Cullen scholars for their support, guidance and luncheons. I acknowledge the financial support received via the Australian Postgraduate Award. I also acknowledge the financial support received from the Association for the Sciences of Limnology and Oceanography and Australian Society of Limnology in helping disseminate my findings.

Much thanks goes to the staff from the NSW Office of Water. Particular thanks goes to Dr John Brayan, Adam, Ellie, Yunis, John and the other staff of the Wolli Creek laboratory for assistance with sample analysis. Many thanks to Ivor Grown for advice and guidance. Thanks to Dave Ryan for field assistance and advice. Thanks to Doug Westhorpe for the advice and the pina coladas. Thanks to Tsuyoshi Kobayashi for advice on bacteria and zooplankton. Thanks to Dan Roelke for helping our mesocosms not disappear to the depths of the estuary.

Special thanks must go Ann-Marie Rohlf. Ann-Marie rode shotgun in the boat and car for most of the last year four years, even when we weren't quite sure how to operate either. Sharing our time between the ice of the snowy mountains and sand of the south coast has been one of the best experiences of this PhD.

Many thanks to Richard Lim for advice, support, and being great company in Taiwan. Thanks to my office buddies Steff and Bec for their support and good times. Thanks to the staff at UTS including Peter, Gemma, Sue, Jane, Rod and Jason. Thank you Darren Baldwin, Joel Hoffman and other anonymous reviewers for their helpful comments.

I would like to extend a massive thank you to all my friends that have helped out. Huge thanks to Carla Thomas for help in the field and for all the microscope hours. Big thanks to Hannah Walters for her help on the microscope, boat and salad rolls. Thanks to Patch Sinclair for the plankton pictures. Thanks to Jordan Iles for his help during field work. Thanks to Dayna Williams, Alice Blackwood, Chris Moore and Emma Kefford for their help. Much thanks to my number one champs Tessa Rex and Jess Minshall.

Thanks to my family who have always been supportive in my endeavours doing “...something about the water”. Finally the biggest thanks and love to my best buddies Beck and Charlie. I could totally have done this without you, but what would have been the point?

## Preface

This thesis consists of seven chapters. Chapters two to six are self-contained and written as journal articles and have either been published, are under revision or soon to be submitted. I have presented them here similar to their published or submitted form and as a result some repetition occurs. These papers are presented in a logical theoretical order. Where these papers cross reference each other I have included chapter numbers. To prevent unnecessary duplication, a single reference list is provided at the end of the thesis. In addition because Chapters two to six are co-authored papers there is a shift from singular, I, to the plural we, within the text.

This thesis is a compilation of my own work with guidance from my supervisor and others. I conceptualized my research, conducted all data collection and analysis, and wrote the manuscripts. My supervisors and co-authors proof-read and edited the final manuscript versions. Publication details and Contributions of co-authors are detailed below:

**Chapter 2:** Hitchcock, J. N and Mitrovic, S. M. 2014. Highs and Lows: the effect of differently sized freshwater inflows on estuarine carbon, nitrogen, phosphorus, bacteria and chlorophyll *a* dynamics. *Estuarine, Coastal and Shelf Science*. In press, doi:10.1016/j.ecss.2014.12.002

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

**Chapter 3:** Hitchcock J. N. and Mitrovic, S. M. 2015. After the flood: Changing dissolved organic carbon bioavailability and bacterial growth following inflows to estuaries. *Biogeochemistry*. In press, doi:10.1007/s10533-015-0094-3

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

**Chapter 4:** Hitchcock, J.N. & Mitrovic, S.M. 2013, 'Different resource limitation by carbon, nitrogen and phosphorus between base flow and high flow conditions for estuarine bacteria and phytoplankton', *Estuarine, Coastal and Shelf Science*, vol. 135, pp. 106-15.

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

**Chapter 5:** Hitchcock, J. N., Mitrovic, S. M., Hadwen, W. L., Growns, I. O. and Rohlfs, A. 2014. Zooplankton responses to freshwater inflows and organic matter pulses in a wave-dominated estuary. *Marine and Freshwater Research*. In prep.

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

W. L. Hadwen provided conceptual advice, guidance and sample analysis relating to stable isotopes.

I. O. Growns provided conceptual advice and guidance.

A. Rohlfs provided field assistance.

**Chapter 6:** Hitchcock, J. N., Mitrovic, S. M., Hadwen, W. L., Roelke, D. L., Growns, I. O. and Rohlfs, A. 2014. Chapter 6 Terrestrial dissolved organic carbon subsidises estuarine zooplankton: an *in-situ* mesocosm study. *Limnology and Oceanography*, In prep.

S. M. Mitrovic gave conceptual advice, guidance and field assistance.

W. L. Hadwen provided conceptual advice, guidance and sample analysis relating to stable isotopes.

D. L. Roelke provided conceptual advice, guidance and field assistance.

I. O. Growns provided conceptual advice and guidance.

A. Rohlfs provided field assistance.

**Other papers published during my candidature but not forming part of this thesis:**

Mitrovic, S.M., Westhorpe, D.P., Kobayashi, T., Baldwin, D.S., Ryan, D., Hitchcock, J.N., 2014. Short term changes in zooplankton density and community structure in response to different sources of dissolved organic carbon in an unconstrained lowland river: evidence for food web support. *Journal of Plankton Research*, vol. 36, pp 1488-1500



# Contents

Acknowledgements .....	iii
Preface .....	v
Contents .....	vii
List of Figures .....	ix
List of Tables .....	xii
List of Abbreviations .....	xiii
Abstract .....	xv
Chapter 1 Introduction .....	1
1.1 Scope and need for this study .....	1
1.2 Freshwater inflows and allochthonous organic carbon inputs to estuaries .....	2
1.3 Bacteria and organic carbon .....	5
1.4 Zooplankton, inflows and the microbial loop .....	6
1.5 Study sites .....	9
1.6 Aims and overview .....	11
Chapter 2 Highs and Lows: the effect of differently sized freshwater inflows on estuarine carbon, nitrogen, phosphorus, bacteria and chlorophyll <i>a</i> dynamics .....	15
2.1 Abstract .....	15
2.2 Introduction .....	16
2.3 Methods .....	16
2.4 Results .....	21
2.5 Discussion .....	34
Chapter 3 After the flood: Changing dissolved organic carbon bioavailability and bacterial growth following inflows to estuaries .....	42
3.1 Abstract .....	42
3.2 Introduction .....	42
3.3 Methods .....	45
3.4 Results .....	50
3.5 Discussion .....	59
Chapter 4 Different resource limitation by carbon, nitrogen and phosphorus between base flow and high flow conditions for estuarine bacteria and phytoplankton .....	65
4.1 Abstract .....	65
4.2 Introduction .....	65

4.3 Methods.....	67
4.4 Results .....	71
4.5 Discussion .....	79
4.6 Conclusion.....	85
Chapter 5 Zooplankton responses to freshwater inflows and organic matter pulses in a wave-dominated estuary.....	87
5.1 Abstract .....	87
5.2 Introduction .....	87
5.3 Methods.....	90
5.4 Results .....	94
5.5 Discussion .....	105
Chapter 6 Additions of dissolved organic carbon from terrestrial sources subsidise estuarine zooplankton: an <i>in-situ</i> mesocosm study.....	113
6.1 Abstract .....	113
6.2 Introduction .....	113
6.3 Methods.....	1136
6.4 Results .....	121
6.5 Discussion .....	132
Chapter 7 General Discussion and Conclusions .....	138
7.1 Discussion .....	138
7.2 Further research.....	145
7.3 Management recommendations.....	148
7.4 Conclusions .....	149
References .....	152

## List of Figures

Figure 1.1 The microbial loop. This is an updated version reprinted from Fenchel (2008). Broken lines represent relationships added since the original paper of Azam et al. 1983. Reprinted with permission from Elsevier. 7

Figure 1.2 Bega and Clyde Rivers. Boxes represent the estuary and main study areas. Different stations were examined in each chapter; locations of these sites are listed in each chapter respectively. 10

Fig 1.3 Conceptual approach to research. Chapters 2 and 5 used a monitoring approach, which helped inform the *in-situ* and *in-vitro* experiments of chapters 3, 4 and 6. Chapters 2 through 4 focus on DOC and bacteria, whilst chapters 5 and 6 focus on zooplankton. 11

Figure 2.1 Map of the Bega and Clyde River catchments, NSW, Australia. Numbers indicate sampling stations. In each river, station 1 is located in the freshwater tidal zone, whilst station 5 is the most marine. 19

Figure 2.2. Time series of discharge and organic carbon values at sampling station 1 on the A) Bega and B) Clyde Rivers, May 2010 to October 2012. Closed circles indicate dissolved organic carbon and open circles particulate organic carbon. NB: sampling was carried out before but not directly after the largest flood in April 2011. 23

Figure 2.3. Time series of discharge and nutrients at sampling station 1, May 2010 to October 2012. A) TN and TP on the Bega River, B) TN and TP on the Clyde River. 25

Figure 2.4. Mean concentrations of various constituents at stations 1 to 5 under flood, fresh and base flow categories. A) DOC Bega River, B) DOC Clyde River, C) POC Bega River, D) POC Clyde River, E) TN Bega River, F) TN Clyde River, G) TP Bega River, H) TP Clyde River, I) Turbidity Bega River, J) Turbidity Clyde River, K) Chlorophyll *a* Bega River, L) Chlorophyll *a* Clyde River, M) Bacterial biomass Bega River, N) Bacterial biomass Clyde River, O) Salinity Bega River, P) Salinity Clyde River. Error bars are  $\pm$  standard error. 26

Figure 2.5. Results of the multiple stepwise linear regression analysis for DOC on the Bega and Clyde Rivers at sampling station 5. A) Ln DOC vs Ln 10 day antecedent discharge on the Bega River, B) Ln DOC vs Ln 10 day antecedent discharge on the Clyde River, C) Ln DOC vs Ln Chlorophyll *a* on the Bega River, D) Ln DOC vs Ln Chlorophyll *a* on the Clyde River. Closed circles are samples taken during flood and flow conditions, open circles are samples taken during base flow conditions. The overlap between flood+fresh and base flow points indicate dates when conditions had returned to base flow however mean daily discharge was still high, predominantly in April and May 2012. 28

Figure 2.6. Results of the multiple stepwise linear regression analysis for POC, TN, TP and turbidity on the Bega and Clyde Rivers at sampling station 5. A) Ln POC vs Ln discharge, Bega River, B) ) Ln POC vs Ln 10 day antecedent discharge, Clyde River, C) Ln TN vs Ln discharge Bega River, D) Ln TN vs Ln 10 day antecedent discharge, Clyde River, E) Ln TP vs Ln discharge, Bega River, F) Ln TP vs Ln 10 day antecedent discharge, Clyde River, G) Ln turbidity vs Ln discharge, Bega River, H) Ln turbidity vs Ln 1 day antecedent discharge, Clyde River. 29

Figure 2.7. Results of the multiple stepwise linear regression analysis for bacterial biomass on the Bega and Clyde Rivers. A) Ln bacterial biomass vs Ln TP, Bega River, station 1, B) Ln bacterial biomass vs Ln TP Clyde River, station 1, C) Ln bacterial biomass vs Ln DOC, Bega River, station 5, D) Ln bacterial biomass vs Ln 10 day antecedent discharge, Clyde River, station 5 32

Figure 3.1. Map of the Bega and Clyde River catchments, NSW, Australia. Samples were taken at the tidal limit of each estuary. 46

Figure 3.2. Time series of discharge and initial dissolved organic carbon values, March to July 2012 on the A) Bega River and B) Clyde River. 51

Figure 3.3. Mean Dissolved organic carbon bioavailability results on the Bega and Clyde Rivers, March to July 2012. A) short and long-term bioavailable DOC on the Bega River, B) short and long-term bioavailable DOC on the Clyde River, C) short and long-term percent bioavailability on the Bega River, D) short and long-term percent bioavailability on the Clyde River. Error bars are  $\pm$  standard error,  $n=2$ . 54

Figure 3.4. Mean Bacterial growth rates and efficiencies on the Bega and Clyde Rivers March to July 2012. A) bacterial growth rates on the Bega River, B) bacterial growth rates on the Clyde River, C) bacterial growth efficiency on the Bega River, D) bacterial growth efficiency on the Clyde River. Error bars are  $\pm$  standard error,  $n=2$ . 56

Figure 3.5. Multiple-regression analysis for long term bioavailable DOC and bacterial growth rates. A) LTC vs  $\ln Q_{10}$  on the Bega River, B)  $\ln BGR$  vs  $\ln Q$  on the Bega River, C) LTC vs  $\ln Q_{10}$  on the Clyde River, D)  $\ln BGR$  vs  $\ln Q$  on the Clyde River. 59

Figure 4.1 Map of the Bega and Clyde River catchments, NSW, Australia. Arrows indicate location of experimental sites which were in the freshwater tidal zone. 68

Figure 4.2 Discharge for the Bega and Clyde Rivers, October 2010 to December 2011. Arrows indicate the dates experiments commenced. 71

Figure 4.3 Bacterial biomass for each bioassay experiment. For each experiment treatments receiving glucose (C) alone or in combination with nitrate (N) and phosphate (P) are separated from treatments which received N and P alone or in combination for ease of viewing. (A-B) Bega River November 2010, (C-D) Bega River January 2011, (E-F) Bega River November 2011, (G-H) Bega River December 2011, (I-J) Clyde River November 2010, (K-L) Clyde River December 2010, (M-N) Clyde River November 2011, (O-P) Clyde River December 2011. Controls are displayed on each graph. Error bars are  $\pm$  standard error ( $n=3$ ). 74

Figure 4.4 Chlorophyll *a* concentrations at 72 hours for each experiment. Where no bar/data is displayed chlorophyll *a* was below methodological detection limits. A) Bega River November 2010, B) Bega River January 2011, C) Bega River November 2011, D) Bega River December 2011, E) Clyde River November 2010, F) Clyde River December 2010, G) Clyde River November 2011, H) Clyde River December 2011. Error bars are  $\pm$  standard error ( $n=3$ ). 76

Figure 5.1. Bega River estuary, south-east Australia. Inset: the tidal section with sampling stations 1 and 2. 90

Figure 5.2. Water quality and biological parameters on the Bega River, January to October 2012. A) discharge and temperature; B) salinity; C) total nitrogen and total phosphorus; D) dissolved organic carbon; E) bacterial biomass; F) chlorophyll *a*. Error bars are  $\pm$  standard error,  $n=3$  95

Figure 5.3. Zooplankton density on the Bega River, 31 January to 17 October 2012. A) rotifer density; B) cladocera density; C) nauplii density; D) copepod density. Error bars are  $\pm$  standard error,  $n=3$  97

Figure 5.4. Relative assemblage structure on the Bega River, 31 January to 17 October 2012. A) Phytoplankton genera at station 1 and B) station 2; C) copepods at station 1 and D) station 2; E) cladocera at station 1 and, F) station 2 99

Figure 5.5. Redundancy analysis of zooplankton and environmental variables for samples collected from the Bega River between 31 January and 17 October 2012. A) Rotifer analysis; B) cladocera analysis; C) copepod analysis. Abbreviations for environmental variables: Temp= temperature,  $Q_{10}$ = mean 10 day antecedent discharge, ChA= chlorophyll a, Sal= salinity, Cop= copepods copepod, Clad= cladocera, NP= nauplii, Rt= rotifers. Abbreviations for zooplankton tested: A) ASP= *Asplanchna*, BRA= *Brachionus*, COL= *Colurella*, DIC= *Dicranophorus*, EPI= *Epiphanes*, KER= *Keratella*, LEC= *Lecane*, LEP= *Lepandella*, PHI= *Philodinae*, POLY= *Polyarthra*, SYN= *Synchaeta*, TES= *Testudinella*, TRI= *Trichocera*; B) BM= *Bosmina meridionalis*, MT= *Moina Tenuicornis*, DP= *Daphnia carinata*, IL= *Ilocrptus* sp., CH= *Chydros* sp.; C) BK= *Boeckella* sp., MSC= *Mesocyclops* sp., GF= *Gladioferens pectinatus*; SC= *Sulcanus conflictus*, HP= harpacticoida. 100

Figure 5.6. Stable isotope  $\delta^{13}\text{C}$  results on the Bega River between 28 February and 17 October, at A) station 1 and; B) station 2. Shaded areas represent the range of  $\delta^{13}\text{C}$  signatures from source materials, light grey= terrestrial plants; dark grey= soils; black= algal. 103

Figure 6.1. Experimental design for mesocosm experiment on the Bega River. The smaller plastic bags are the 400L mesocosm, whilst the larger outside structure protects the bags from damage. Inset adding DOC leachate at day 0. 119

Figure 6.2. Water quality during the mesocosm experiment, Bega River. A) Temperature; B) DOC; C) DIN; D)  $\text{NH}_4$ ; E) DON; F) DIP. Error bars are  $\pm$  standard error,  $n=5$  for control and  $n=3$  for treatments. 123

Figure 6.3. Biological parameters during the mesocosm experiment, Bega River. A) Dissolved oxygen; B) Bacterial biomass; C) Chlorophyll a. Error bars are  $\pm$  standard error,  $n=5$  for control and  $n=3$  for treatments. 125

Figure 6.4. Zooplankton density during the mesocosm experiment, Bega River. A) Nauplii; B) Rotifers; C) *Gladioferens pectinatus* copepodites; D) *Gladioferens pectinatus* adults, E) *Sulcanus conflictus* copepodites, F) *Sulcanus conflictus* adults, G) Other zooplankton. Error bars are standard error,  $n=5$  for control and  $n=3$  for treatments. 129

Figure 6.5. Initial and day 22 stable isotope  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  signatures during the mesocosm experiment, Bega River. Horizontal line indicates  $\delta^{13}\text{C}$  signature of the DOC leachate. GP = *Gladioferens pectinatus*, SC = *Sulcanus conflictus*. Error bars are  $\pm$  standard error. For G. pectinatus  $\delta^{13}\text{C}$   $n=5$  for control,  $n=3$  for treatments and for  $\delta^{15}\text{N}$   $n=2$ . For S. conflictus only one pooled sample for control and each treatment was measured. 131

Figure 7.1. Conceptual diagram of the major findings of this thesis. 138

## List of Tables

Table 2.1. Results of PERMANOVA analysis, Bega and Clyde Rivers. Pseudo *F*-values, degrees of freedom (df) and *P*-values on the Bega and Clyde River. 27

Table 2.2. Multiple stepwise regression analysis for DOC, POC, TN, TP, turbidity and chlorophyll *a* on the Bega and Clyde Rivers. The best fit models were created with a single variable in most cases. Where no equation is listed, no significant relationship could be found between the dependent and any independent variable. All models were validated using the bootstrapping procedure in SPSS Ver. 21 and had significance values <0.05. 33

Table 3.1. Initial water quality and environmental variables on the Bega and Clyde Rivers, March to July 2012. Carbon and nutrient concentrations were taken at Day 0 of the experiment. Chlorophyll *a*, SUVA and discharge values reflect conditions on the initial day of sampling. Error is standard error, *n*=3. 52

Table 3.2. Results of PERMANOVA analysis. Pseudo *F*-values, degrees of freedom (df) and *P*-values for DOC bioavailability and bacterial growth rate and efficiency on Bega and Clyde Rivers. 57

Table 3.3. Multiple-regression results for the Bega and Clyde Rivers. Stepwise backward elimination was used to find the model which explained the most variance for each dependent variable. Only models that that were significant, *P*<0.05, are listed. 58

Table 4.1. Initial conditions and ambient carbon and nutrient mean concentrations at the start of the bioassay experiments, Bega and Clyde Rivers. Error is standard error (*n*=3). \**n*=1, other replicates <1 µg L<sup>-1</sup>. 72

Table 4.2. Pseudo *F*-values, degrees of freedom (df) and *P*-values of bacterial biomass and chlorophyll *a* of main factors and interactions from PERMANOVA analyses for the bioassay experiments. nt= not tested 78

Table 4.3. Summary of primary and secondary factors limiting bacterial and phytoplankton growth on the Bega and Clyde Rivers. \*Co-limitation. 78

Table 5.1. Results of redundancy analysis for rotifers, cladocera and copepods on the Bega River, January to October 2012. 101

Table 5.2. List of phytoplankton and zooplankton taxa found on the Bega River Estuary, January to October 2012. 104

Table 6.1 Pseudo *F*-values, degrees of freedom (df) and *P*-values for water quality and zooplankton from PERMANOVA analyses. GP = *Gladioferens pectinatus*, SC = *Sulcanus conflictus*. nt=not tested. \*denotes failed Permdisp test and significance considered *P*<0.01 124

Table 6.2. Results of Permnova t-test pairwise comparisons, treatments vs days, for DOC, nutrients, dissolved oxygen and bacteria. Only significant (*P*<0.05) values are listed. \*denotes failed Permdisp test and significance considered *P*<0.01. 127

Table 6.3. Results for Permanova monte-carlo pairwise comparisons treatments vs days. Only significant (*P*<0.05) values are listed. GP = *Gladioferens pectinatus*, SC = *Sulcanus conflictus*, Cop = copepodites. 130

## List of Abbreviations

BB	Bacterial biomass
BDOC	Bioavailable dissolved organic carbon
BGE	Bacterial growth efficiency
BGR	Bacterial growth rate
C	Carbon
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DON	Dissolved organic nitrogen
DNP	Dissolved non-reactive phosphorus
FWI	Freshwater inflows
LTB%	Long-term percent carbon bioavailability
LTC	Long-term bioavailable dissolved organic carbon
N	Nitrogen
P	Phosphorus
POC	Particulate organic carbon
$Q$	Mean daily discharge
$Q_{10}$	Mean 10 day antecedent discharge
STB%	Short-term percent carbon bioavailability
STC	Short term bioavailable dissolved organic carbon
SUVA	Specific ultra-violet light absorption
TN	Total nitrogen
TP	Total phosphorus
WSP	Water sharing plan





## Abstract

Freshwater inflows (FWI) play a crucial role in maintaining estuarine processes and productivity. River regulation and extraction have greatly reduced FWI to estuaries. Little attention has been paid to the role FWI has in delivering organic carbon to estuaries. The aim of this thesis was to define the relationship between freshwater inflows, organic carbon, bacteria and zooplankton dynamics. To do this, I performed a series of monitoring and experimental studies on the Bega and Clyde River estuaries, Australia.

Discharge on both rivers was highly episodic during the study. On the Bega and Clyde Rivers, increasing dissolved organic carbon (DOC) concentrations were closely coupled with increasing discharge. The bioavailability of DOC increased during FWI events, and in turn bacterial growth rates were also higher during and immediately following inflow events. Bacterial growth was carbon limited most of the time, though during high flows, bacteria often became phosphorus limited. Changing availability of DOC and phosphorus during inflow events was the main reason for shifting resource limitation. On both rivers bacterial biomass was positively related to increasing DOC and phosphorus concentrations. Highly episodic discharge during this study had a major structuring role over carbon and bacteria dynamics.

On the Bega River I found strong evidence that allochthonous carbon and bacteria can subsidise zooplankton production following the input of DOC during FWI events. Zooplankton density increased following a flooding event on the Bega River and stable isotope analysis indicated allochthonous terrestrial carbon was the dominant source of carbon utilised by zooplankton. Experimental mesocosms confirmed that allochthonous carbon and bacteria can support increased zooplankton in the presence of high subsidies.

The individual studies forming this thesis all contribute new insights to their respective sub-disciplines within aquatic ecology. Viewed together, they present a novel conceptualisation of hydrology and freshwater inflows in the coastal carbon cycle and microbial food webs in south-east Australian estuaries. The results provide a strong case to protect freshwater inflows to estuaries.

